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Dual Port Asymmetrical Cascaded H-Bridge Multilevel Inverter

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***Abstract*— The current research scope has been taken as Multilevel Inverter (MLI) concept development, realization, and performance evaluation for stable energy conversion in hybrid energy systems. The inverter developed is a dual, port design that can connect two independent DC sources such as a renewable energy source and an energy storage system, thereby increasing the operational flexibility and energy management capacity.An asymmetrical DC voltage configuration is used to generate more output voltage levels with fewer power switches, which results in a lower circuit complexity, less cost, and higher efficiency. The working principle is initially laid down by an operation analysis of a five, level MLI, then the design and experimental implementation of a seven, level MLI are done for post voltage accuracy and harmonic performance.A PWM technique is utilized for switching angles optimization, which almost completely eliminates the reduction of THD. Both the simulation and the hardware experiments prove the proposed topology capability to deliver efficient power utilization, stable operation, and high, power quality in renewable and hybrid energy applications.**

***Index Terms*— Cascaded H-bridge Inverter, Asymmetrical, Total Harmonic Distortion, Pulse Width Modulation.**

I. INTRODUCTION

The deployment of renewable energy systems and distributed generation has been rapidly expanded. Due to that, it is more important than ever to have efficient DC-AC conversion with improved power quality. Two, level inverters that are conventional have a drawback of producing high harmonic distortion (THD), leading to more switching losses and less waveform quality. Thus, their usage in medium, and high, power applications is highly limited. Multilevel inverters (MLIs), especially the cascaded H-bridge (CHB) topology, solve these problems by producing stepped output voltages that very closely resemble a sinusoidal waveform, which results in lower THD and fewer filter requirements. On the other hand, symmetrical CHB inverters need multiple isolated DC sources and lots of switches, thus increasing the cost and complexity of the system. Asymmetrical CHB configurations are able to address those problems by using unequal DC source voltages to get higher voltage levels with fewer components leading to better voltage utilization and harmonic performance.This paper introduces a dual-port asymmetrical cascaded H-bridge multilevel inverter that is capable of integrating a photovoltaic (PV) source and a battery storage unit in a single structure.

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A boost DC-DC converter is used to regulate the PV voltage, and the asymmetrical arrangement allows for the generation of seven-level output through PWM control. The system in question has been simulated and analyzed in Simulink and experimentally validated with an IGBT, based hardware prototype. A comparison has been made between the five-level symmetrical and seven-level asymmetrical configurations which shows that there is an improvement in the output voltage quality and a decrease in the THD, thus emphasizing the proposed topology suitability for hybrid renewable energy applications.

II. Related Work or Literature Studies

Multilevel inverters (MLIs) are a major component in the efficient conversion of DC-AC power in modern power electronic systems, especially in hybrid and renewable energy systems. When compared to standard two-level inverters, MLIs produce stepped output voltages that are very similar to sinusoidal waveforms, hence, they enhance power quality and reduce harmonic
distortion. One of the MLI topologies is a cascaded H-Bridge (CHB) inverter which is favored the most because of its modular structure, scalability, and straightforward control scheme [1], [4].
However, symmetrical CHB structures necessitate several isolated DC sources and a lot of switches to be able to raise the voltage level, which leads to more expense and system complexity. Asymmetrical CHB inverters solve this problem by using different DC voltage ratios, which allow for higher voltage levels with fewer switches and better voltage utilization [5], [6].
Current research is generally about dual-port CHB inverters that can house two DC sources of different voltages within one converter. In hybrid energy systems, a boost converter is usually involved to raise the battery voltage to the level of the photovoltaic (PV) voltage, thus leading to higher system efficiency and the elimination of multiple conversion stages [7]. Motivated by these ideas, this paper demonstrates a 7-level asymmetrical CHB inverter with dual, source integration. The proposed three-phase inverter, supplied by a DC source through an impedance network, generates high-quality AC output, offering an effective solution for multilevel DC–AC power conversion [11], [12]. Therefore, the proposed topology provides a convenient solution for multilevel DC-AC transformation.

III. Motivation

This work was mainly triggered by the necessity of efficient power conversion in hybrid renewable energy systems since the traditional and symmetrical inverter designs usually result in higher losses, cost, and hardware complexity. The proposed system through the utilization of an asymmetrical voltage configuration integrated with multiple DC sources in a single topology achieves higher power quality, less total harmonic distortion (THD), and lower component requirements.

IV. Problem Domain

Power Electronics converters for drives and generators. The present work focuses on power electronics for the integration of renewable energies. Specifically, it's about DC-AC conversion for hybrid energy systems consisting of solar photovoltaic units and batteries. The major issues to be addressed are to the raise the inverter efficiency, the reduction of harmonic distortion and the stabilization of the operation under the fluctuation of source conditions.

V. Problem Definition

The key problem addressed in this paper is the development of an inverter topology that:

- Effectively combines several DC sources
- Produces high, quality AC output with low THD
- Utilizes fewer power switches
- Continues to be realistic for hardware implementation

VI. Statement

To design and develop a dual-port asymmetrical cascaded H-Bridge multilevel inverter that can generate a seven-level AC output of high quality with low harmonic distortion and low hardware complexity suitable for hybrid renewable energy applications.

VII. Innovative Content

The novel part of this paper mostly revolves around the work on the inverter stage, and this has been further developed through simulation to cover performance evaluation in depth. Some of the main innovative ideas are:

- Design and hardware implementation of a dual, port asymmetrical cascaded H-Bridge (CHB) multilevel inverter, thus allowing the mixing of two independent DC sources in one inverter topology.
- Application of asymmetrical DC voltage ratios for obtaining higher output voltage levels with fewer power semiconductor switches, hence the circuit is less complicated and the voltage utilization is better.
- Combining directly multiple DC sources at the inverter level to reduce the effective power conversion stages, therefore the overall system efficiency is increased.
- Testing and confirming the inverter stage experimentally via an IGBT, based prototype, which has been used to demonstrate the generation of five, level symmetrical and seven, level asymmetrical outputs.
- Thorough simulation, based performance analysis first of all regards PV integration, then continues with and without the LC filter usage, and next presenting a detailed THD evaluation for determining the waveform quality under different working conditions.

VIII. Problem Formulation or Representation of Design

A Multilevel Inverter is an inverter device that changes direct current (DC) into alternating current (AC) by generating multiple voltage levels in the output waveform.

A. Multilevel Inverter Topologies

- Neutral Point Clamped or Diode-Clamped MLI: It uses clamping diodes to connect the switch output to intermediate voltage levels between the positive and negative DC rails.
- Flying Capacitor MLI: It replaces the diodes with capacitors to produce intermediate voltage levels.
- Cascaded H-Bridge MLI: A CHB MLI composed of several H-Bridge cells that are linked in series to generate a multilevel ac output from different dc sources.

Types of Cascaded H-Bridge MLI:

- Symmetrical Cascaded H-Bridge MLI
- Asymmetrical Cascaded H-Bridge MLI

Table I: Comparative Analysis of Symmetrical and Asymmetrical CHB Inverter

Aspect	Symmetrical CHB MLI	Asymmetrical CHB MLI
DC Source Magnitudes	All H-bridge cells use equal voltage	H-bridge cells use unequal voltages
Number of Output Levels	Fewer levels for same number of cells	More levels with same number of cells
Output Voltage Steps	Evenly spaced steps (e.g., -2V, -V, 0, V, 2V)	Uneven steps (e.g., -7V, -3V, -V, 0, V, 3V, 7V)
Harmonic Performance	Good, but fewer levels → higher THD	Better THD due to more voltage levels
Efficiency	Lower compared to asymmetrical	Higher due to fewer switches for the same quality output

A comparison between symmetrical and asymmetrical CHB multilevel inverters is presented in Table I. The table highlights the main differences in the configuration parameters and the switching requirements of the two topologies.

IX. System Design and Switching Table of the Proposed Inverter

A. Design Methodology of the Proposed Inverter

The inverter under consideration features an CHB asymmetrical MLI topology comprising a fewer number of power switches. To obtain a five-level output voltage and to facilitate the correct operation of the inverter, a suitable switching strategy has been adopted.

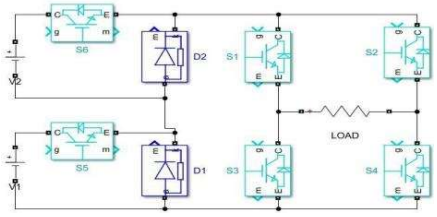

Figure 1: Optimized MLI Configuration

The design of the MLI is depicted in Fig. 1. The figure illustrates the positioning of the power switches and their wiring, which are employed to produce various output voltage levels.

B. Switching Table of the Proposed Inverter

The proposed inverter switching table displays the different switching combinations. It shows the creation of different output voltage levels corresponding to these combinations.

TABLE II: INVERTER SWITCHING COMBINATIONS

Voltage Levels	S1	S2	S3	S4	S5	S6	Modes
+V1	1	0	0	1	1	0	Mode 1
+V2	1	0	0	1	0	1	Mode 2
+(V1+V2)	1	0	0	1	1	1	Mode 3
+V2	1	0	0	1	0	1	
+V1	1	0	0	1	1	0	
0	0	0	1	1	0	0	Mode 4
-V1	0	1	1	0	1	0	Mode 5
-V2	0	1	1	0	0	1	Mode 6
-(V1+V2)	0	1	1	0	1	1	Mode 7
-V2	0	1	1	0	0	1	
-V1	0	1	1	0	1	0	
0	0	0	0	1	1	0	

The switching combinations of the proposed inverter are shown in Table II which also presents the output voltage levels resulting from each configuration. This serves as a precise guidance to the inverter operation in different switching scenarios.

C. Parameter Computation

The primary design parameters of the inverter are set to guarantee its correct functioning and the accurate generation of voltage levels.

TABLE III: SIMULATION PARAMETERS

Parameters	Values
PV Voltage	40 V
PV Side Capacitor	100µF
Boost Inductor	2.1mH
Boost Output Capacitor	1500µF
Duty Cycle	80%
Switching Frequency	15kHz
Boost Output Voltage(V2)	200V
DC Voltage Source(V1)	100V
Output Voltage	180V
Output Power	480W
Output Frequency	50Hz
Load (R)	66.7Ω
Filter Inductor	5mH
Filter Capacitor	20µF

The parameter values for CHB inverter are summarized in Table III. These parameters are selected to assess the performance of the system during PV and battery source operation.

X. SIMULATION RESULT AND ANALYSIS

The detailed simulations evaluate the dual-port inverter performance by analyzing output waveforms and comparing THD to demonstrate harmonic improvement under different operating conditions.

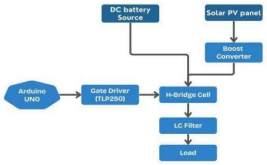

Figure 2: Block Diagram of DPAMLI

The conception of Asymmetrical CHB MLI is visually represented in Fig. 2. The schematic demonstrates the successful coupling of a renewable source and a storage device to provide high, quality AC output at top efficiency with less harmonic distortion.

A. CHB Inverter with dual DC sources

The dual DC source CHB inverter functions by adding the voltages of two independent DC sources to produce a multilevel AC output. Such a setup offers the freedom of different voltage levels and improved power quality.

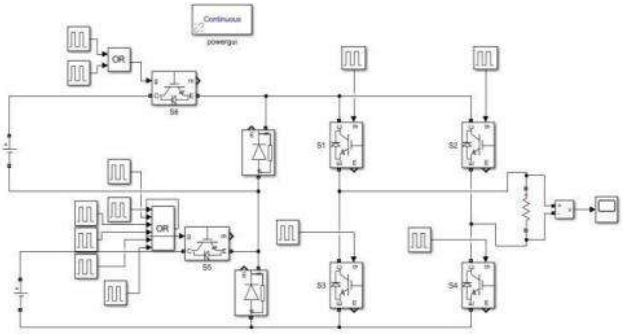

Figure 3: Simulation model of CHB-MLI

The simulation model of the proposed topology is presented in Fig. 3. The performance of the inverter is examined using this model.

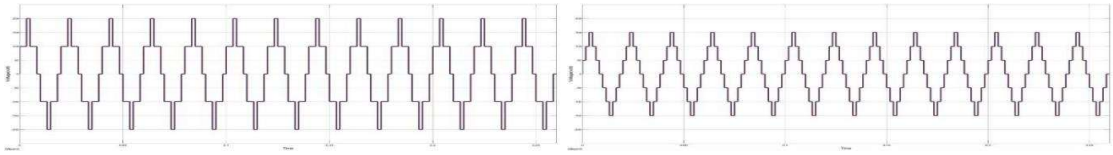

Figure 4: Symmetrical five-level and Asymmetrical Seven-level CHB inverter's output voltage waveform with equal DC source voltages.

For analysis, a Cascaded H-Bridge (CHB) inverter with two DC sources is considered under both symmetrical and asymmetrical configurations is shown in Fig. 4. In the symmetrical case ($V_1 = V_2 = 100$ V), the inverter produces a five-level sinusoidal output waveform. In the asymmetrical configuration ($V_2 = 2V_1$, with $V_1 = 50$ V and $V_2 = 100$ V), the inverter generates a seven-level sinusoidal output waveform, demonstrating an increase in voltage levels with unequal DC sources.

B. Proposed System of the Dual Port CHB Inverter

The dual-port CHB inverter system comprises two different power sources, a DC source, and a PV array. As a result, the system can operate in a hybrid mode, which yields a stable AC output of lower harmonics and higher efficiency.

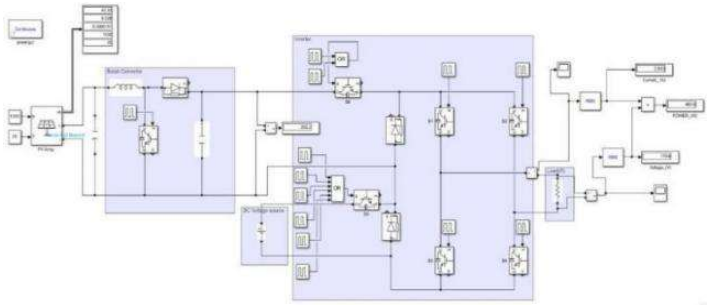

Figure 5: Prototype of the CHB inverter powered by PV and battery sources.

The illustration in Fig. 5 depicts a CHB inverter with PV and battery as the two power sources. The topology enables the independent coupling of the renewable and the storage sources. Reduced harmonic distortion and effective energy utilization are facilitated through the operation of the inverter.

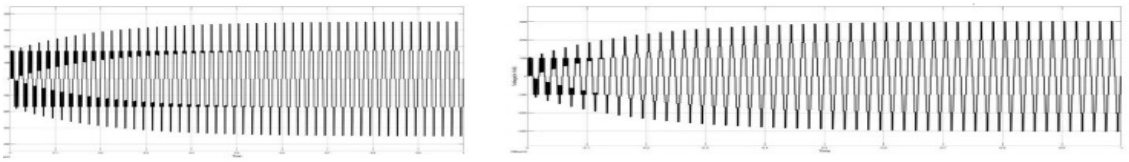

Figure 6: Output waveform of the symmetrical and asymmetrical inverter using PV array and DC source voltage.

The output voltage waveform of the CHB inverter with a PV array and a DC source is shown in Fig. 6. Under symmetrical operation, the inverter produces a five-level stepped waveform, confirming proper multilevel performance.

At the moment of starting, there is a temporary voltage increase that can be explained by the charging of the DC, link capacitor and the behavior of the boost converter. The system stabilizes at about 0.54 s and after this time the output voltage of the system shows a distinct seven, level structure with significantly lowered harmonics, thus visually depicting the improvement of the output voltage quality.

IX. Solution Methodology or Problem Solving

The parts of the proposed dual, port asymmetrical CHB inverter that have been emphasized for physical implementation are the inverter stages. These inverter stages have been realized using IGBT, based H-Bridge modules so that the practical operation of the topology can be verified.

A. TLP250 Gate Driver Circuit

The TLP250 optocoupler gate driver is used to provide electrical isolation and fast switching control between the Arduino PWM controller and the power IGBTs of the multilevel inverter.

The gate drive outputs corresponding to switches, T1, and T2 are taken from the TLP250 driver circuit.

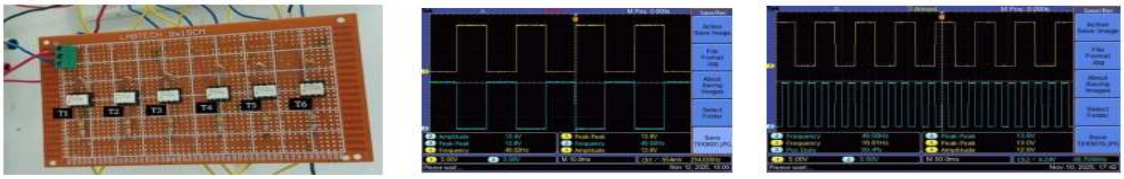

Figure 7: Opto-isolated gate driver circuit for inverter switches and gating pulse of T1&T2 and T5&T6

The gate driver circuit which is utilized for the driving of the inverter switches is depicted in Fig. 7. A regulated 1215 V DC supply is given to the Vcc of the TLP250 so as to provide the necessary voltage at the gate of the IGBTs for performing operations efficiently and reliably. The outputs of the gate drive for switches T1, T2, T5, and T6 essentially illustrate that switching pulses have been properly generated from the TLP250 driver circuit hence driver performance is correct.

B. Proposed Dual-Port CHB Inverter

The proposed dual, port CHB inverter is executed in hardware with an IGBT, based power circuit. The experimental setup illustrates the genuine working of the inverter topology and its switching operation.

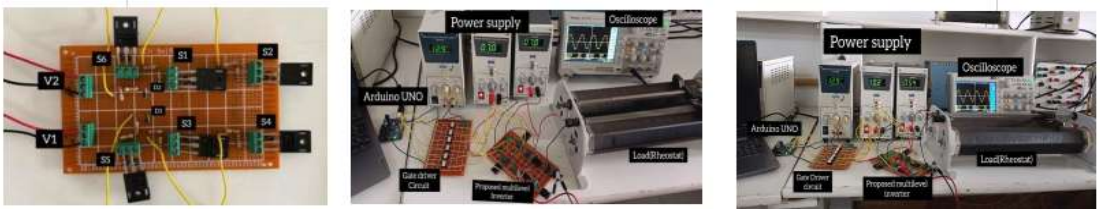

Figure 8: Hardware setup of the proposed dual-port CHB inverter

Fig. 8 presents the hardware realization of the CHB inverter, which displays the symmetrical and asymmetrical configurations. In the symmetrical mode, the H-bridges receive identical DC voltages, resulting in the balanced operation of the inverter stages.

X. Result and Sensitivity Analysis

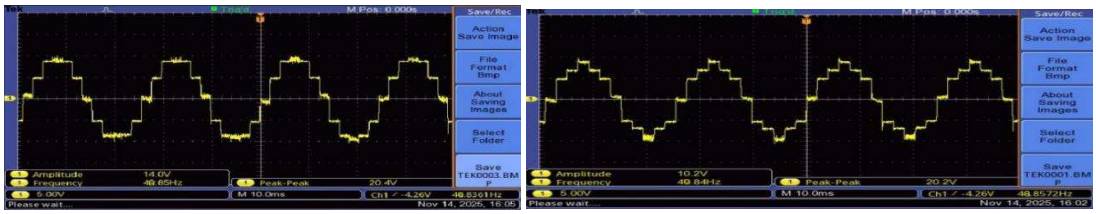

Figure 9: Output waveform of five and seven level DPAMLI

The output waveform of the seven-level dual-port asymmetrical MLI is shown in Fig. 9. The figure illustrates the multilevel stepped voltage waveform produced by the inverter.

XI. Data Model

The data model includes:

- DC input voltages from PV and battery
- PWM gating signals
- Output voltage waveforms
- Harmonic spectra and THD values
- Load parameters and filter component

XII. Comparison of Results

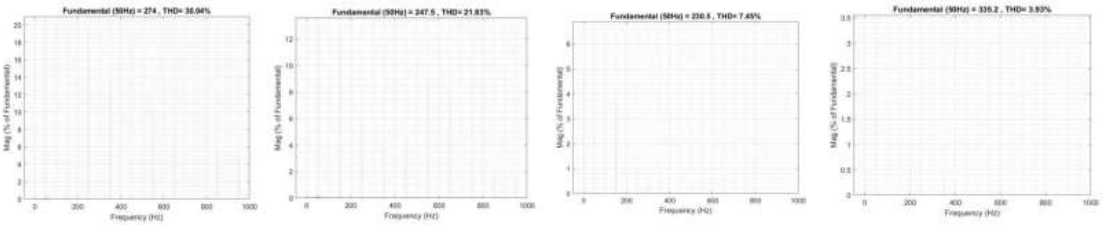

Figure 10: THD of the symmetrical and asymmetrical inverter output voltage with and without filter

The harmonic spectrum of the CHB inverter output is shown in Fig. 10.

TABLE IV: THD Comparison of Five and Seven Level CHB Inverter Outputs

Inverter Configuration	Output Voltage Levels	THD
Symmetrical CHB Inverter	Five Level	30.04%
Asymmetrical CHB Inverter	Seven Level	21.83%
Symmetrical CHB Inverter With Filter	Five Level	7.45%
Asymmetrical CHB Inverter WIth Filter	Seven Level	3.93%

The comparative THD analysis is shown in Table IV,reveals that the seven-level CHB inverter has a lower harmonic distortion than the five-level one, even in the absence of an output LC filter. The higher number of voltage levels enhances the waveform approximation to a sinusoid, which leads to a decrease in THD.

XIII. Conclusion

In this work, a dual-port asymmetric multilevel inverter fed from a photovoltaic source with a boost DC–DC converter was designed and its performance evaluated using MATLAB/Simulink. To demonstrate how filtering affects waveform quality, the inverter's operation was examined both with and without an output LC filter. The harmonic performance of 5-level symmetric and 7-level asymmetric inverter configurations was compared. According to simulation results, when using an LC filter, the 7-level asymmetric inverter achieves a significantly lower THD of 3.93%, while the 5-level asymmetric inverter displays a THD of 7.45%. The seven-level configuration has a better harmonic profile due to a greater number of voltage levels and the output filter's efficient harmonic attenuation. In addition, the hardware implementation of the inverter stage which achieved five-level and seven-level output voltages, was in itself a successful experiment and thus, it practically confirms

the viability of the proposed topology. Hence, the seven-level asymmetric multilevel inverter with an output LC filter can be considered as a suitable source of high, quality, low, harmonic AC power for renewable energy applications.

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